Sustainable supplier performance scoring using audition check-list based fuzzy inference system: a case application in automotive spare part industry

Abstract

With the global awareness of sustainability issues, sustainable development is being increasingly recognized by governments and industries. In addressing these issues, organizations worldwide have taken initiatives in adopting sustainability practices in their supply chain transferring it to sustainable supply chain management. In order to establish a responsible sustainable supply chain management, an effective way would be to make sure that the potential suppliers for procuring required components are precisely assessed and evaluated based on sustainable criteria. Therefore, this paper proposes a practical decision making approach to evaluate and select the most sustainable suppliers for an automotive spare part manufacturer licensed under a France-based automotive organization. Firstly, a requirement gathering approach, the audition check-list approach, is designed to facilitate the process of data gathering for supplier evaluation based on three pillars of sustainability. Next, the gathered data are processed using a proposed fuzzy inference system to remove impreciseness and vagueness in the gathered sustainability related data. The strength of this model falls into its applicability in data gathering phase which helps decision makers in manufacturing company to perform a fast audition of a typical supplier. Secondly, the final sustainable ranking of suppliers using the proposed fuzzy inference system provide a precise and less uncertain sustainability performance scoring which makes the developed approach a reliable system for making sustainable sourcing decisions. Comparison and sensitivity analysis are performed to evaluate the proficiency of the developed approach. Finally, theoretical and managerial implications together with conclusions of the study are presented.

Keywords: Supply chain management; Sustainability; Supplier selection; Fuzzy inference system; Social sustainability; Supplier audition

1. Introduction

Recently, many manufacturing companies are forced by their internal and external stockholders such as end customers and Original Equipment Manufacturing (OEM) firms to ensure that their manufacturing and supply chain (SC) activities are keeping the pace with environmental and social developments (Vachon & Klassen, 2008; Zimmer et al., 2015). The basic concept of SCM has been extended by sustainable supply chain management (SSCM) by considering sustainability dimensions resulting in better performance (Meixell & Luoma, 2015). The greater expectation in improving the performance in an organizations' corporate activities with regards to all three sustainability dimensions can be an important driver for managers to consider SSCM (Azadi et al., 2015; Beske & Seuring, 2014).

Traditionally, making sourcing decisions were based on cutting costs where environmental and social efficiency of suppliers were neglected (A. Kumar et al., 2014). However, more and more sustainable legislations are now forcing industrial practitioners to practice the integration of sustainability Triple Bottom Line (TBL) attributes (environmental, economic and social) into their production and SC activities (Meixell & Luoma, 2015; Seuring & Müller, 2008). Maintaining competitive advantage in the global market is highly dependent on an integrated design of the entire SC network. This integrated network would facilitate the flow of information and materials between suppliers and end-customers by focusing on planning and management. Within this integrated view, fulfilling customers' orders could be highly influenced by suppliers. Therefore, appropriate evaluation and selection of suppliers greatly affects the entire supply network (Azadnia et al., 2014; Özgen et al., 2008). As addressed by Longoni and Cagliano (2015), smaller manufacturing organizations that act as suppliers for bigger focal forms are more likely to lose their competitive advantages by just focusing on their cost-based business configuration models. Therefore, their traditional operations need to be enriched and expanded by incorporating environmental and social sustainability dimensions.

In practice, various challenges such as global sourcing, new competitors and technological developments are always involved in automotive industry (Çifçi & Büyüközkan, 2011; Kannan et al., 2013; A. Kumar et al., 2014; Li & Zhao, 2009). Nowadays, these challenges are blended with sustainability awareness among the stakeholders (bigger organizations and end-customers) which makes bigger organizations to be concerned about their supplier management practices. In the automotive industry, first-tier suppliers play an important role in design and manufacturing of components rather than just producing predesigned products (Lockstroem et al., 2010). Therefore, selecting the most sustainable suppliers that can produce sustainable components is of great importance.

In SSCM literature, various methodologies and models are developed and utilized for sustainable supplier evaluation and selection. Some of these applied techniques include fuzzy analytical hierarchy process (FANP) (Buyukozkan & Cifci, 2011), decision-making trial and evaluation laboratory (DEMATEL) (Chiou et al., 2011), fuzzy analytical hierarchy process (FAHP) (Chiouy et al., 2011), fuzzy inference system (FIS) (Amindoust et al., 2012), fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Govindan (Govindan, Kannan, et al., 2013) and data envelopment analysis (DEA) (Shi et al., 2015). There are also few research activities that tried to combine two or more techniques in order to form a hybrid approach that could perform better than its constituting techniques individually. For example, some of these hybrid approaches include AHP-quality fuzzy deployment (QFD) (Dai & Blackhurst, 2012) and FAHP-neural network (NN)-TOPSIS (Azadnia et al., 2012).

The main focus of this research study is to evaluate and select the most sustainable supplier for a manufacturing company that is aiming to upgrade its manufacturing and sourcing activities in a more sustainable manner. This company (S.S Company) is acting as a first tier supplier for a bigger firm in France. They are obligated to procure sustainable components for the mother company. The S.S Company has already a supplier evaluation system that considers criteria such as quality (Q), technical capability (TC), production capacity (PrC) and geographical location (GL) for supplier selection. The current research establishes a sustainable supplier selection system for this case company where a data gathering approach is designed namely, audition check-list approach that handles providing the initial evaluation data regarding each dimension of sustainability (10 criteria established for 3 identified suppliers for sustainable evaluation). Although this approach provides initial values for the sustainability attributes, these values are uncertain and imprecise in nature; therefore, the results of this audition check-list approach are process using the developed FIS resulting into more precise decision-making assistance for the S.S Company managers. The strength of this model is its applicability in the data gathering phase using the developed audition check-list approach which helps the decision makers in a manufacturing company to perform a fast audition of a typical supplier. Secondly, the final sustainable rankings of suppliers provided by the proposed FIS are precise which makes the approach a reliable system for making sustainable sourcing decisions.

The reminder of this paper is structured as follows: a literature review is provided in Section 2 with focus on SSCM, Fuzzy-set theory-based sustainable supplier evaluation techniques and sustainable supplier selection criteria. Section 3 provides the research design of this paper focusing on the theoretical underpinnings of our research based on the literature review presented in Section 2. Section 4 gives the details of the proposed approach. In Section 5, the utilization of the developed approach and computational results are presented based on the case application. Section 6 presents the results analysis and discussions. Section 7 presents the implications for theory and practice based on the research findings. Finally, some remarks and future avenues of research are concluded in Section 8.

2. Literature review

2.1 SSCM practices

During the last couple of decades, SSCM has been considered by organizations in various types of industries (Blome et al., 2014; Faisal, 2010; Huq et al., 2014; Quariguasi Frota Neto et al., 2010; Roehrich et al., 2014) with many special issues in high ranked journals and also conferences. In a most recent special issue called, Sustainable operations management: recent trends and future directions (Walker et al., 2014). Blome et al. (2014) utilized structural equation modelling (SEM) to investigate the effects of dedicating companies' resources toward sustainable practices in a systematic manner. Testing various hypotheses, it was concluded that coordinating with suppliers and customers in a sustainable manner is not possible without required capabilities inside an organization. Quariguasi Frota Neto et al. (2010) investigated the possibilities of transiting from closed loop SCs to SCs. It was found that managers trying to move toward sustainable SCs first should take measures that can improve the sustainable performance more effectively through the critical life-cycle stages. Roehrich et al. (2014) investigated the effects of being involved in environmental and socially responsible SCM from the view point of a manager/decision maker inside an organization. They concluded that reputational risk exposure derives the decisions of moving towards a SSCM among the decision makers and it was suggested that an appropriate relationship and collaborations of the manufacturer organization with its upstream suppliers can help to share the risk. Finally, it should be highlighted that orientation of a company towards sustainability and SSCM is deeply depending on dedicating the strategic level decisions of a company towards sustainable practices. This matter requires SSCM to be incorporated into the mind-set of any typical company rather than just an ordinary corporate practice (Beske & Seuring, 2014; Pagell & Wu, 2009).

2.2 Sustainable supplier evaluation and selection tools combined with fuzzy set theory

Based on the literature review results presented in Ghadimi et al. (2015) and Govindan, Rajendran, et al. (2013), fuzzy set theory combined with other tools such as ANP, AHP, DEMATEL and TOPSIS is the most common utilized approach in sustainable\green supplier selection. Fuzzy logic was introduced for the first time in 1965 by Zadeh (1965). It is widely used to elicit expert knowledge and model the human thinking process. The use of fuzzy logic techniques allows weaving a quantitative method into a qualitative representation (Carrasco et al., 2002). The inherent vagueness and complexity of sustainability concept makes it difficult to measure or define. The systematic procedure in handling vague circumstances where traditional mathematics are deemed inefficient makes fuzzy logic to be a natural technique to assess sustainability (Phillis & Andriantiatsaholiniaina, 2001). The performance evaluation of an organization toward a goal can be based on imprecisely defined inputs that are quantitative or qualitative in nature. Although some of the input values can be calculated precisely, the valid range of the values is divided into classes or fuzzy sets

(Afrinaldi & Zhang, 2014). Natural uncertainty, ambiguity and intangibility that exist in the sustainability attributes provide justifications on utilizing fuzzy analysis in the process decision-making.

Additionally, utilization of fuzzy logic reasoning can be justified based on the following two basic features: (1) it has the ability to deal with ambiguous concepts that are hard to quantify. Therefore, reasoning with such ambiguous concepts may not be clear and obvious, but rather fuzzy. (2) Mathematical tools are provided by fuzzy logic in order to handle problems mixed with subjectivity resulting in concrete outputs (crisp). Dynamics of a system can be modelled using fuzzy logic without undergoing much detailed mathematical description (Ghadimi et al., 2012; Phillis & Andriantiatsaholiniaina, 2001). Table 1 sheds light into some of the recently published approaches in terms of the purpose of developing such an approach together with the sustainable element considered in each of these research activities.

Table 1.
Fuzzy Logic combined with other tools.

Author(s)	Research objective	Proposed approach	Assessment criteria orientation
Awasthi et al. (2010)	Assess the experts score and provide a final ranking for each supplier	Fuzzy-TOPSIS	Green
(Shen et al., 2013)	Generate the overall performance score of each supplier.	Fuzzy-TOPSIS	Green
Govindan et al. (2012)	Evaluate suppliers based on TBL attributes.	Fuzzy-TOPSIS	Sustainable
(Kannan, Jabbour, et al., 2014)	Selecting green suppliers based on green supply chain management practices	Fuzzy-TOPSIS	Green
Buyukozkan and Cifci (2011)	Address sustainable supplier selection problem in a real-world case study in Turkish white goods industry	Fuzzy-ANP	Sustainable
Wang et al. (2012)	Develop a fuzzy CBR approach in a virtual enterprise framework to select the suppliers based on quantitative criteria.	Fuzzy-case-based reasoning (CBR)	Green
Bali et al. (2013)	Develop an approach to cope with situations with partially known and unknown information.	Fuzzy-grey relational analysis (GRA)	Green
Kannan, Kannan, et al. (2014)	Performing a real world case study related to green supplier selection practice.	Fuzzy Axiomatic Design	Green
Orji and Wei (2015)	Select the best sustainable supplier based on their performance towards sustainability over a time horizon	Fuzzy-System Dynamic	Sustainable

2.3 Determination of the sustainable supplier evaluation and selection criteria

The work performed by Noci (1997) was the first research that reported the design of a supplier rating system that incorporated environmental sustainability in the process of supplier evaluation. After that, various environmental sustainability criteria and sub-criteria are proposed and categorized by distinguished scholars in the field of sustainable/green supplier selection (Awasthi et al., 2010; Chunguang Bai & Joseph Sarkis, 2010; Hsu & Hu, 2009; Kannan, Jabbour, et al., 2014; Lee et al., 2009). Recently, Kannan, Jabbour, et al. (2014) reported an appropriate categorization of evaluation criteria and their influencing factors associated with green supplier selection. They presented four main criteria for economic sustainability i.e. quality, price, delivery and service. The categorized main criteria for environmental sustainability are environment protection/environment management, management system, pollution control, green product, green image, green innovation, environmental performance, hazardous substance management.

Although manufacturing more environmental friendly products and components would yield huge advantage to the overall profitability of a SC, a more practical consideration of social dimension criteria are also essential (Longoni et al., 2015; Meixell & Luoma, 2015; Stefan Schaltegger et al., 2014; Zimmer et al., 2015). Considering social aspects of sustainability could be even more challenging in comparison with integrating environmental aspects as, for instance, issues such as child labour and diversity in work place due to different cultural and ethical differences in various countries would be difficult to tackle (Zimmer et al., 2015). Another important obstacle in considering social attributes could be also the quantification process of the associated sub-criteria with social dimension of sustainability which was also highlighted by Zimmer et al. (2015) and Ghadimi et al. (2015)

Section 2.3 presents a categorization of criteria and sub-criteria regarding the environmental and social sustainability dimensions based on previously published research activities related to the research domain considered in this paper. These categorizations were adopted from a recent literature review conducted by Ghadimi et al. (2015) (first author of this current paper). The environmental and social dimensions criteria and their sub-criteria are discussed in more details in the following sub-sections.

2.3.1 Environmental performance (Environmental)

Environmental performance (EP) indicates that how well a supplier is performing on driving internal environmental audits as well as aligning with external environmental policies (Azadnia et al., 2014; Büyüközkan, 2012; Dou et al., 2014; Kannan, Kannan, et al., 2014; Mafakheri et al., 2011; Tuzkaya, 2013; Zhu et al., 2010). It includes environmental protection, green process planning, internal control process, continuous monitoring and regulatory compliance, environment-related certificates and environmental protection policies (Ghadimi et al., 2015). Shen et al. (2013) emphasized the fast growing awareness of people between economy and environment and mentioned the important role of environmental management systems and policies in mitigation of environmental impacts.

2.3.2 Green image (Environmental)

The Green image (GI) criterion deals with establishing the supplier company’s business image in the market place as a green supplier with the capability of manufacturing green products which provides a distinctive advantage in the market (Awasthi et al., 2010; Bali et al., 2013; Kannan, Kannan, et al., 2014; Mafakheri et al., 2011; Tuzkaya, 2013). Green image includes market share, stakeholders’ relationships, customer retention, market reputation and staff environmental training (Ghadimi et al., 2015). Kannan, Kannan, et al. (2014) stated that keeping those customers that are more willing to purchase green products can be one of the influential factors in measuring green image of a typical supplier.

2.3.3 Pollution control (Environmental)

The pollution control (PC) criterion deals with controlling supplier's various types of gas emissions level to be aligned with manufacturer's and local/global authorises' environmental policies depending on the type of industry (Amin & Zhang, 2012; Hsu et al., 2013; Kannan, Kannan, et al., 2014; A. Kumar et al., 2014; Mafakheri et al., 2011; Tuzkaya, 2013). The involved sub-criteria in PC are waste water, resource consumption, carbon footprint, air emissions, use of harmful materials and solid wastes (Ghadimi et al., 2015). A. Kumar et al. (2014) considered carbon footprinting in their supplier assessment. They mentioned that full carbon footprinting contains a wide range of emissions and therefore can be an appropriate indicator in pollution control. Based on a analysis by Hsu et al. (2013), suppliers with established management system for collecting carbon emissions data from their manufacturing activities on organizational or product level might have competitive advantage.

2.3.4 Green competencies (Environmental)

Green competencies (GC) criterion deals with measuring the ability of a supplier in reducing the ecological impacts of its operations using various green technologies available such green packaging and recycling (Amin & Zhang, 2012; Awasthi et al., 2010; Çifçi & Büyüközkan, 2011; Ghadimi & Heavey, 2014; Mafakheri et al., 2011). Use of environmental friendly materials, green packaging, recycling capability, responsiveness, flexibility and green technology are the sub-criteria related to green competencies (Ghadimi et al., 2015). Çifçi and Büyüközkan (2011) stated that supplier's capacity in manufacturing products that incur low impact on natural resources should of the main concerns in considering this criterion in supplier's assessment.

2.3.5 Green design (Environmental)

Green design (GD) criterion measures the capability of a supplier in terms of deigning environmental friendly products (Mafakheri et al., 2011; Tuzkaya, 2013; Yeh & Chuang, 2011). Recycle, reuse, refurbish, remanufacture, disassembly, disposal are categorized at the effecting sub-criteria to green design criterion (Ghadimi et al., 2015). Yeh and Chuang (2011) pointed out that recycling, reusing and reproducing certain substances need to be prohibited in being contained in products design.

2.3.6 Health and safety (Social)

Health and safety (HS) criterion measures a supplier's capability in terms of providing effective systems to protect employees (Azadnia et al., 2014; C. Bai & J. Sarkis, 2010; Dai & Blackhurst, 2012; Ghadimi & Heavey, 2014; Govindan, Khodaverdi, et al., 2013; Wittstruck & Teuteberg, 2012). OHSAS 18001, health and safety incidents, standardized health and safety conditions and health and safety practices are the identified sub-criteria for this main criterion (Ghadimi et al., 2015). In studies conducted in China (W. Yu et al., 2012; Yuan et al., 2012), the importance of selecting suppliers that consider safety-related behaviours and safety standards in their workspaces is emphasized due to a significant increase in industrial accidents and work-related injuries (Thornton et al., 2013).

2.3.7 Employment practices (Social)

Employment practices (EmP) criterion deals with valuing the employees of an organization by ensuring to meet their current and future needs (Azadnia et al., 2014; Baskaran et al., 2012; Buyukozkan & Cifci, 2011; Govindan, Khodaverdi, et al., 2013). This criterion encompasses the sub-criteria such as child labour, flexible working arrangements, employee contracts, diversity, job opportunities, discrimination, employment compensation, the interests and rights of employee, career development, equity labour sources, employee welfare, research and development and disciplinary and security practices (Ghadimi et al., 2015). Labuschagne et al. (2005) also defined employment practices as a measure to ensure that an employer complies with the existing national and international laws and human rights regarding its employees. In their study in Indian textile industry, Baskaran et al. (2012) highlighted long working hours and using child labour as the most influential sub-criteria in evaluating a supplier regarding social aspects of sustainability. Culpan and Guglielmo (2010) stated that SC globalization could have direct impact on awareness and human rights treatments for workforces in geographically dispersed suppliers. Thornton et al. (2013) identified this matter as an important focus by manufacturing firms in seeking for suppliers that paying attention to human right issues such as discrimination are being highly established as an organizational mind-set.

2.3.8 Local communities influence (Social)

The local communities influences (LCI) criterion measures the contributions of a supplier to its local communities (C. Bai & J. Sarkis, 2010; Baskaran et al., 2012; Dai & Blackhurst, 2012; Govindan, Khodaverdi, et al., 2013; Thornton et al., 2013). The sub-criteria that are involved in this criterion are regulatory and public services, security, grants and donations, service infrastructure, health, mobility infrastructure, supporting educational institutions, education, economic welfare and growth, social cohesion, housing, supporting community projects (Ghadimi et al., 2015). Thornton et al. (2013) pointed out the community focus that a manufacturing firm could be looking for while selecting its suppliers. They mentioned that bigger organizations might be concerned by the negative influence of the suppliers on the local communities.

2.3.9 Contractual stakeholders influence (Social)

Contractual stakeholders influence (CSI) criterion measures the interest level of a supplier as a primary stakeholder in establishing a long-term relationship with the company (C. Bai & J. Sarkis, 2010; Chiouy et al., 2011; Govindan, Khodaverdi, et al., 2013; Thornton et al., 2013). The CSI criterion contains sub-criteria such as information disclosures, stakeholder engagement, partnership screens and standards, procurement standard, stakeholder empowerment, consumer’s education and decision influence potential (Ghadimi et al., 2015). Dai and Blackhurst (2012) investigated the influence of customers and stakeholders on producing socially responsible products. The effect of this type of requirement was considered in developing social development strategies such as providing good job opportunities and promoting a sage and healthy workplace.

Building on the theoretical background of the SSCM and sustainable supplier selection problem discussed in this section, the next section elaborates on the various gaps that have been identified during the study of the literature which also formed our research motivations.

3 Research design

There are many studies that investigate the effect of incorporating environmental and economic aspects of the TBL into the supplier selection process (C. Bai & J. Sarkis, 2010; Çifçi & Büyüközkan, 2011; Dou et al., 2014; Kannan, Kannan, et al., 2014; A. Kumar et al., 2014; Shaw et al., 2013; Shen et al., 2013; C. Yu & Wong, 2014). Besides, a few studies have also considered social aspects of the TBL in the supplier selection either combined with environmental and economic dimensions or in a separate manner (Amindoust et al., 2012; Baskaran et al., 2012; Buyukozkan & Cifci, 2011; Govindan, Khodaverdi, et al., 2013). However, based on a recent empirical study by Longoni and Cagliano (2015) and Meixell and Luoma (2015), it was highlighted that incorporating TBL attributes into traditional operations strategies are still at its early stages and more comprehensive treatments should be made to address all three TBL dimensions. The developed approach in this research applied on a case company in automotive spare part industry narrows this gap in the literature. The following paragraphs explain the advantages of combining two techniques in the proposed approach for sustainable supplier evaluation and selection.

Section 2 states that gathering data regarding supplier evaluation from the TBL perspective is difficult and time consuming (Baskaran et al., 2012; Büyüközkan, 2012; Lee et al., 2009; Parthiban et al., 2013; J.-R. Yu & Tsai, 2008). These practical issues were also identified by Danese (2013) where they analysed the added values of time-efficient supplier integration (SI) approaches in a supply network of buyer organizations. Their findings emphasize the need for practical supplier selection approaches that try to provide a means for appropriate adoption of suppliers in order to structure buyers' supply network in an efficient and flexible manner. This gap is addressed by developing an audition check-list as part of the proposed sustainable supplier selection approach that allows buyer organizations to efficiently evaluate their potential suppliers.

Although the above mentioned sustainable supplier assessment approach provides concrete output values, however the inherent subjectivities in the audition process by manufacturer company's supplier auditors can result in a biased supplier assessment. Therefore, the audition-based approach is combined with a developed FIS model forming an approach to overcome such subjectivities in sustainable supplier selection decision making process. The proposed FIS is applicable to this work as it can provide a way for managers to characterize the inputs (criteria) and the decision threshold (supplier's sustainability performance score) by providing a single number score in order to show the level of performance of each of the suppliers towards each of the sustainability dimensions. As a result, the proposed approach results in an enhanced evaluation process for suppliers who incorporate sustainability principles into their operations and manufacturing activities.

4 Proposed approach

The methodology foresees the following five steps (Fig. 1):

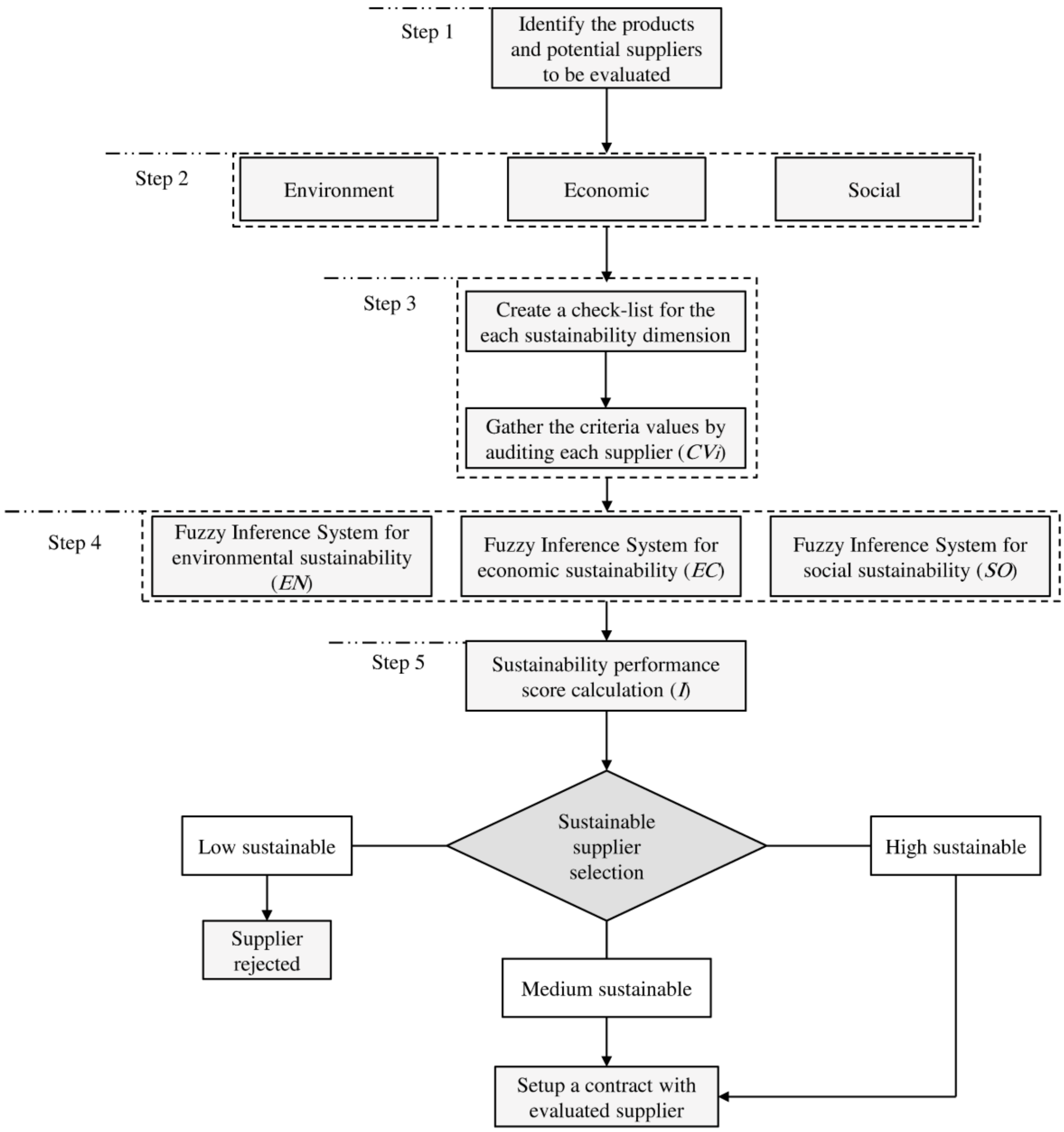


Fig. 1 near here

Step 1: is involved in finding the possible suppliers that are capable of providing the required products needed by a manufacturer. This step can be done by joint efforts with the purchasing department of the manufacturer company using existing suppliers' historical records in the manufacturer company.

Step 2: is about selecting all criteria and their sub-criteria for each of the sustainability dimensions (i.e. environmental, economic and social). The selection of these criteria and their sub-criteria is based on the categorized criteria and their sub-criteria presented in section 2.3. In the presented case study, this selection has been validated through a structured manner based on the DMs involvement inside the case company (see step 2 in Section 5).

Step 3: deals with designing the audition check-lists and evaluating potential suppliers that are identified in step 1. The supplier audit check-list will be created according to each sustainability dimension and its respective criteria and sub-criteria defined in step 2. Experts in buyer organization will define questions in a check-list format for each criterion to be completed upon auditing a supplier by audition experts of buyer firm. Each question will be given appropriate "ranking order" by auditor based on his observations of the supplier's company. The audit process is carried out to determine whether the supplier meets the requirements (expected by manufacturer) with respect to the designed check-list for each sustainability dimension. In the auditing process, the auditor visits the supplier company to gather the required values based on the designed check-lists. A Sample of the developed audition check-list for social sustainability dimension is provided in the Appendix which is related to the case study reported in Section 5. After performing the auditions, the value for each criterion related to each of the three sustainability dimensions (between 0 and 1) is calculated based on Eq. 1 as follows:

$$CV_i = \frac{\sum_{k \in K} r_{ki}}{\sum_{k \in K} R_{ki}} \qquad i \in I \tag{1}$$

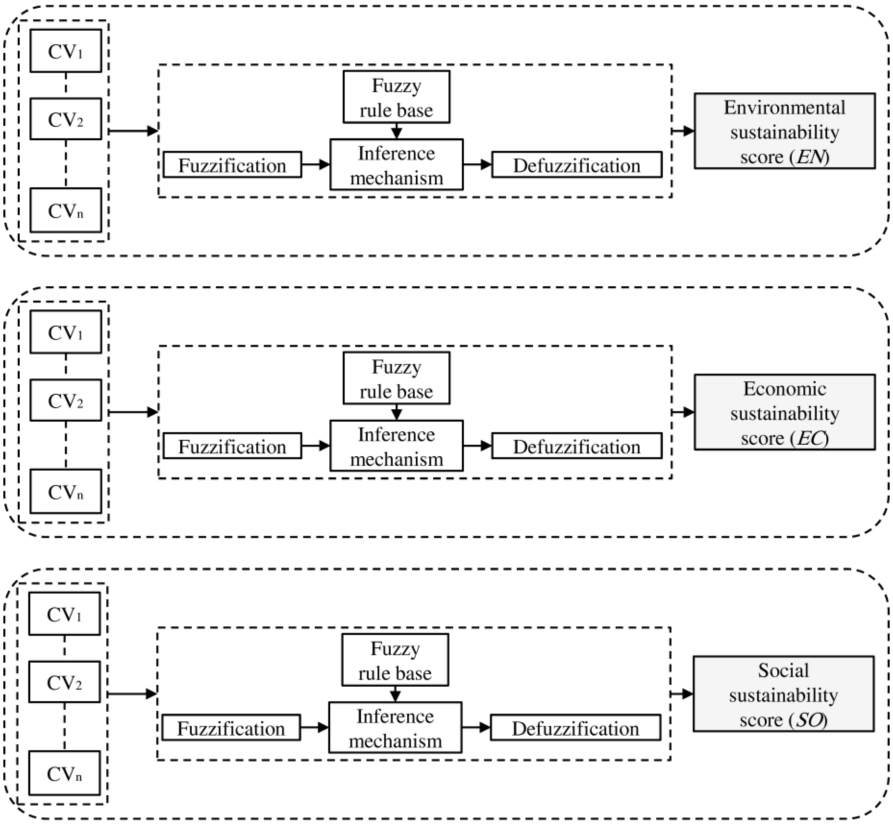
where,

CV_i	Obtained value of i^{th} criterion.
r_{ki}	The value of the question k answered by the auditor for criterion i.
R_{ki}	The maximum possible value of the question k for criterion i.
k	Question index.
K	Total number of questions; $k \in K$.
i	Criterion index; $i \in I$.

Step 4: explains the fuzzy evaluation part. In this research, Mamdani's compositional rule of inference (Mamdani, 1974) has been applied to build the proposed FIS model. It consists of four operational steps that are described in the followings.

(a) Fuzzification: this is the step performed to assess the input data. Gathered subjective and imprecise data in step 3 are converted into grades of membership. Purchasing manager or a CEO inside the organization sets these grades of membership based on the importance and criticality of input variables (selected criteria in step 2). Next, a target range is to be set for each input variable. A target range would be the minimum and maximum values that the input variable value can obtain. The source of selecting a target range might be various depending on the nature of the input variable. A common source for defining a target range could be set by local authorities, the manufacturer and national agencies. Instead of considering a fixed and predefined target range for all of the selected criteria, the input variables target ranges are not predefined in this proposed approach and can be defined based on the manufacturers companies priorities. This will eventually result in a more reliable approach that incorporates DMs' opinions and priorities providing a more precise decision making system. These target ranges are then utilized in constructing the membership functions.

In this research work, we have one membership function that has been incorporated in the proposed FIS model depicted in Fig. 2. This membership function is set out for measuring a supplier's performance towards each sustainability dimension. In this FIS model, three fuzzy sets are applied for the inputs that are the criteria. The linguistic rating variables assigned to each of these fuzzy sets are "low", "medium" and "high" as shown in Fig. 3(a) and tabulated in Table 2. The fuzzy sets are based on target ranges described in the previous paragraph, say [a c].



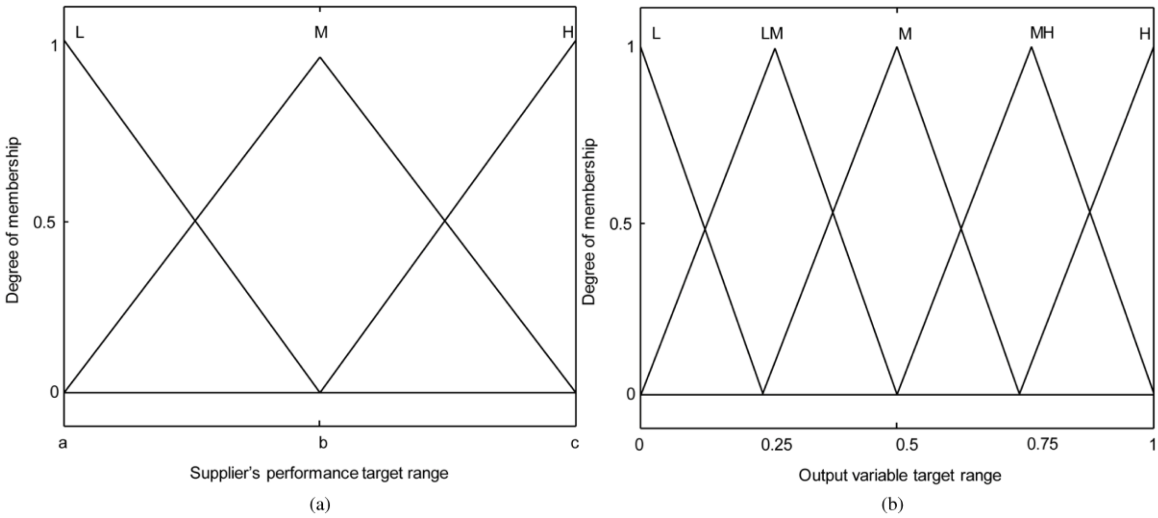
[Fig. 2 near here]

Table 2.
The Linguistic terms for supplier's performance measurement.

Linguistic terms	Fuzzy set
Low (L)	(a, a, b)
Medium (M)	(a, b, c)
High (H)	(b, c, c)

The input variables membership function developed for the proposed FIS is considered using a triangular form. A triangular form fuzzy number can be shown as $\widetilde{\mathrm{T}} = (\mathrm{a}, \mathrm{b}, \mathrm{c})$ and defined as Eq. 2.

$$\mu_{\tilde{M}} = \begin{cases} 0, & x < a, \\ (x-a)/(b-a), & a \le x \le b \\ (c-x)/(c-b), & b \le x \le c \\ 0, & x > c \end{cases} \tag{2}$$



[**Fig. 3** near here]

(b) Knowledge base (rules): the rule base will be defined after the input variables membership functions are constructed based on DMs' knowledge inside the organization. The number of rules in the fuzzy rule base can be calculated based on Eq. 3 (Cornelissen et al., 2001):

$$R = n^{v} \tag{3}$$

where the numbers of the input variables membership function are represented by n and v is the number of input variable for each sustainability dimension and R stands for the number of potential rules. Knowledge base will be populated with a series of IF-THEN rules where various criteria are combined with each other to form the IF part and THEN part of the respective sustainability dimension. The number of potential rules increases exponentially if the number of criteria increases for each sustainability dimensions. For instance, for $n = 3$ and $v = 4$ the number of potential rules would be $R = 81$ and for $v = 5$, $R = 243$. In such cases, some realistic rules of the rule base according to company's DMs' knowledge can be defined In those cases, translating the whole knowledge in rules would not be necessary and some of the unnecessary rules can be eliminated (Erozan, 2011).

(c) Fuzzy inference mechanism: the inputs for this fuzzy mechanism are the fuzzified result of each rule and the output of this mechanism will be used as an input for the defuzzification process.

(d) Defuzziefication: the output membership functions are constructed using zero to one target range. The zero value is an indication of a low sustainability performance while one is interpreted as a high sustainability performance. This membership function is set out for aggregating the results of the fuzzy inference mechanism into crisp output which would be the supplier performance score towards the measured dimension. In the developed FIS model, five fuzzy sets and linguistic terms are applied for the output variable membership functions that are each of the sustainability dimensions. The linguistic rating variables assigned to each of these fuzzy sets are shown in Fig. 3(b) and tabulated in Table 3.

Table 3.
The Linguistic terms for each of the output variables.

Linguistic terms	Fuzzy set
Low (L)	(0, 0, 0.25)

Low to Medium (LM)	(0, 0.25, 0.5)
Medium (M)	(0.25, 0.5, 0.75)
Medium to High (MH)	(0.5, 0.75, 1)
High (H)	(0.75, 1, 1)

There are many types of defuzzification methods such as centroid, bisector and Middle, Smallest, and Largest of Maximum. In the proposed FIS, centroid method has been used to perform the defuzzifiction process. Fig. 2 depicts various stages described in Step 5. The final outputs of this step are environmental sustainability score (*EN*), economic sustainability score (*EC*) and social sustainability score (*SO*). These scores are utilized in the calculation process described in step 5.

Step 5: deals with the calculation of supplier sustainability performance score which is the cumulative value of the economic, environmental and social sustainability dimensions weighted scores using Eq. 4:

$$I = \sum w_{ec} EC + \sum w_{en} EN + \sum w_{so} SO \tag{4}$$

where I is the sustainability performance score of the evaluated supplier, w_{ec} is the importance weight of economic sustainability dimension, w_{en} is the importance weight of environmental sustainability dimension and w_{so} is the importance weight of social sustainability dimension. Defining the importance weights is an option that can be considered by the manufacturer company as they might want to consider no priority on the sustainability dimensions. After identifying the sustainability performance score of evaluated supplier, a decision need to be made based on the predefined thresholds. The results in this step decrease the burden of manufacturer company's managers in terms of thinking about making the best sustainable decision towards setting up a contract with evaluated supplier or rejecting it.

5 Case application and results

In this section, the implementation results of the developed approach are provided. The results analysis and discussions are provided in Section 6.

- *Step 1: about the case company*

Apart from the oil and petroleum industry, the automotive industry has an important impact on Iran's economic advantage. Many car companies in Iran are operating under foreign multi-national automotive companies' licence which brings the obligations for Iranian car manufacturing companies to be aligned with the foreign organization's operational visions. S.S Company is a manufacturer of starter motors and alternators for various types of cars. This company is licensed by a multinational automotive spare part manufacturing organization in France. It was established in 1999 and started operation in 2001. It produces starter motors and alternators of large range of automobiles. The S.S Company has obtained the standard marks from the Iranian standard institution, ISO/TS 16949:2002 quality standard certificate in 2004 from RW TUV Germany and ISO 17025.

As the S.S Company is operating under the French organization's missions and standards, they are obliged to operate under sustainability guidelines and initiatives that are requested by the French organization. Therefore, they are taking initial steps to move toward these principles. The applicability and practicality of the proposed approach is shown through the research activity conducted to merge the company's supplier evaluation decisions with the sustainability TBL context. There is a newly lunched assembly process in the S.S Company. The company is seeking to select the most sustainable suppliers for the two components required in the manufacturing process of the Renault Logan namely, front and rear brackets for the starter. Two suppliers are required to source these components. This decision has been made by the company DMs as they try to decrease their number of suppliers in order to develop closer relationships with them. The proposed approach described in Section 4 has been applied to provide reliable results for DMs in the company in order to tackle the supplier evaluation decisions. Three suppliers have been identified by the purchasing department of the S.S company that have the potential to provide the required brackets namely, S.P, T.S and K.KH. However, there is no historical information available about the sustainable performance of these three companies.

- *Step 2: determination of criteria and sub-criteria for the three sustainability dimensions*

In this step, we asked the DMs in the S.S Company (quality control manager, quality assurance manager, production planning manager, and marketing manager) to select the most relevant criteria and sub-criteria for environmental and social sustainability dimensions. This was done using questionnaires developed based on the categorization presented in Section 2.3 asking the DMs whether the presented sub-criteria were relevant for their operations or not. The DMs expressed their ideas they have generated regarding the sub-criteria selection related to each criterion using the distributed questionnaire. Finally, the aggregate opinions on each of the sub-criterion were considered as the final decision on selecting a sub-criterion. Two separate sessions were held for environmental and social sustainability dimensions. Regarding the economic sustainability, quality (Q), technical capability (TC), production capacity (PrC) and geographical location (GL) are the four appropriate criteria. These criteria are suggested by the DMs based on their already established supplier selection system. This research incorporates environmental and social aspects of sustainability into this system. Table 4 tabulates the selected criteria and sub-criteria for social and environmental sustainability dimensions.

Table 4.
Selected criteria and sub-criteria for environment and social sustainability dimensions.

Dimensions	Criteria	Sub-criteria
Environmental sustainability	EP	Environment-related certificates
		Internal control process
		Environmental protection plans
		Environmental protection policies
	GI	Staff environmental training
		Market reputation
		Customer retention
	PC	Air emissions
		Waste water
		Use of harmful materials
	GC	Use of environmental friendly materials
		Recycling capability
		Green packaging
		Responsiveness

Social sustainability	HS	OHSAS 18001 Standardized health and safety conditions Health and safety incidents Health and safety practices
	EmP	Job stability Job opportunities Child labor Flexible working arrangements Employee welfare The interests and rights of employee

- *Step 3: designing the audition check-lists and obtaining the criteria values*

In this step, a set of audition check-list in the form of questions were designed based on the sub-criteria related to each of the selected criterion. Each question is provided by a set of ranking orders for the auditor to choose from such as “yes”, “yes but insufficient”, “no”, “no answer” and also some question specific choices. Due to space limitation, a sample of check-list for social sustainability dimension utilized to audit the three potential suppliers in the current research work is presented in the Appendix (developed check-lists for environmental and economic dimensions are not presented in this paper). The validity of the questions has been approved by the S.S Company’s SC and quality assurance departments’ managers. This process took over a week until final agreements about the content of the designed check-lists were expressed by these executive managers. After validating the audition check-lists, auditors were sent to each of the three suppliers to evaluate their performance regarding the TBL measures using the developed check-lists. Table 5 tabulates the results of the auditions conducted in each of these three supply companies. The calculations are based on Eq. 1.

Table 5.
The criteria values for the three supplier companies.

Dimension	Criteria	S.P company	T.S company	K.KH company
Environmental sustainability	EP	1	0.36	0.91
	GI	0.91	0.64	0.82
	PC	0.62	0.62	0.62
	GC	0.82	0.73	0.73
Economic sustainability	Q	0.905	0.286	0.881
	GL	1	0.909	0.727
	TC	0.87	0.391	0.739
	PrC	1	0.600	0.8
Social sustainability	HS	1	0.5	0.89
	EmP	0.71	0.53	0.65

Table 6 tabulates the audition process result that was obtained by the S.S Company’s supplier audition engineer. In order to illustrate how the audition check-list approach works, the mathematical detail of technical capability criterion for K.KH Company is presented in the following which was calculated using Eq. 1:

$$CV_3 = \frac{\sum_{k=1}^{11} r_{13} + r_{23} + r_{33} + r_{43} + r_{53} + r_{63} + r_{73} + r_{83} + r_{93} + r_{103} + r_{113}}{\sum_{k=1}^{11} R_{13} + R_{23} + R_{33} + R_{43} + R_{53} + R_{63} + R_{73} + R_{83} + R_{93} + R_{103} + R_{113}}$$

$$= \frac{2+1+2+2+1+0+1+2+2+1+3}{2+2+2+2+2+2+2+2+2+2+3} = \frac{17}{23} = 0.739$$

As the above calculation shows, the technical capability criterion value (CV) equals to 0.739 for the K.KH supplier company. The same procedure was performed to calculate the CVs of all the other criteria.

Table 6.
Audition results for technical capability (TC) criterion.

Question no. (Q_{ki})	Question	Ranking order (rate)	Audition result
Q_{13}	Does the supplier have a R&D centre?	Yes (2); No (1)	2
Q_{23}	Suitable inspection equipment available and calibrated?	Yes (2); Yes but insufficient (1); No (0); No answer (0)	1
Q_{33}	Is the supplier capable of producing S.S company’s needed components?	Yes (2); No (1)	2
Q_{43}	Does the supplier have a procedure for maintenance of tools and equipment?	Yes (2); Yes but insufficient (1); No (0); No answer (0)	2
Q_{53}	Is the supplier able to test and simulate products or processes, internally or externally?	Yes (2); Yes but insufficient (1); No (0); No answer (0)	1
Q_{63}	R&D budget allocated as percentages of the turnover?	More than 5% (2); Less than 5% (0)	0
Q_{73}	Supplier’s capacity for innovation on its market (patents ownership, etc.)?	Yes (2); Yes but insufficient (1); No (0); No answer (0)	1
Q_{83}	Is supplier’s CAD system compatible with S.S Company?	Yes (2); No (1)	2
Q_{93}	Are personnel competent for their works?	Yes (2); Yes but insufficient (1); No (0); No answer (0)	2
Q_{103}	Is the preventive maintenance schedule drawn up?	Yes (2); Yes but insufficient (1); No (0); No answer (0)	1
Q_{113}	Do you think that this supplier is capable of working with S.S Co. regarding technical capability criterion?	Perfectly convinced (3); Rather convinced (2); Rather unconvinced (1); Unconvinced (0)	3

- *Step 4: Fuzzy evaluation*

In this step, the four steps of the fuzzy evaluation part that were discussed and presented in Section 4 (step 4) were implemented. Firstly, the crisp input (the *CV* values calculated in step 3) and output variables (environmental, economic and social sustainability scores) are converted into grades of membership, as shown in Tables 7 and 8. Afterwards, the fuzzified variables are utilized to construct a fuzzy rule base. For each sustainability dimension, the number of rules is calculated using Eq. 3. Moreover, the whole knowledge is translated into rules in order to perform a precise assessment. Table 9 shows some rules instances extracted from the rule-base.

Table 7.

Input variables and their membership functions

Linguistics value	Numerical range	Linguistics value	Numerical range	Linguistics value	Numerical range
Environmental sustainability		*Economic sustainability*		*Social sustainability*	
Linguistics variable: EP		Linguistics variable: Q		Linguistics variable: HS	
Low	[0 0 0.5]	Low	[0 0 0.5]	Low	[0 0 0.5]
Medium	[0 0.5 1]	Medium	[0 0.5 1]	Medium	[0 0.5 1]
High	[0.5 0.5 1]	High	[0.5 0.5 1]	High	[0.5 0.5 1]
Linguistics value	Numerical range	Linguistics value	Numerical range	Linguistics value	Numerical range
Environmental sustainability		*Economic sustainability*		*Social sustainability*	
Linguistics variable: GI		Linguistics variable: GL		Linguistics variable: EmP	
Low	[0 0 0.5]	Low	[0 0 0.5]	Low	[0 0 0.5]
Medium	[0 0.5 1]	Medium	[0 0.5 1]	Medium	[0 0.5 1]
High	[0.5 0.5 1]	High	[0.5 0.5 1]	High	[0.5 0.5 1]
Linguistics value	Numerical range	Linguistics value	Numerical range		
Environmental sustainability		*Economic sustainability*			
Linguistics variable: PC		Linguistics variable: TC			
Low	[0 0 0.5]	Low	[0 0 0.5]		
Medium	[0 0.5 1]	Medium	[0 0.5 1]		
High	[0.5 0.5 1]	High	[0.5 0.5 1]		
Linguistics value	Numerical range	Linguistics value	Numerical range		
Environmental sustainability		*Economic sustainability*			
Linguistics variable: GC		Linguistics variable: PrC			
Low	[0 0 0.5]	Low	[0 0 0.5]		
Medium	[0 0.5 1]	Medium	[0 0.5 1]		
High	[0.5 0.5 1]	High	[0.5 0.5 1]		

Table 8.

TBL output variables and their membership functions

Linguistics value	Numerical range	Linguistics value	Numerical range	Linguistics value	Numerical range
Linguistics variable: Environmental		Linguistics variable: Economic		Linguistics variable: Social	

Low	[-0.25 0 0.25]	Low	[-0.25 0 0.25]	Low	[-0.25 0 0.25]
Low to Medium	[0 0.25 0.5]	Low to Medium	[0 0.25 0.5]	Low to Medium	[0 0.25 0.5]
Medium	[0.25 0.5 0.75]	Medium	[0.25 0.5 0.75]	Medium	[0.25 0.5 0.75]
Medium to High	[0.5 0.75 1]	Medium to High	[0.5 0.75 1]	Medium to High	[0.5 0.75 1]
High	[0.75 1 1.25]	High	[0.75 1 1.25]	High	[0.75 1 1.25]

Table 9.
Rule examples from the rule base

Rule no.	Rules
Rule 1	IF environmental performance is low AND green image is low AND pollution control is low AND green competencies is low THEN environmental sustainability is low
Rule 2	IF quality IS low AND geographical location IS low AND technical capability IS low AND production capacity IS high THEN economic sustainability IS low to medium
Rule 3	IF quality IS high AND geographical location IS high AND technical capability IS high AND production capacity IS medium THEN economic sustainability IS medium to high
Rule 4	IF environmental performance is high AND green image is high AND pollution control is high AND green competencies is medium THEN environmental sustainability is medium to high
Rule 5	IF health and safety is high AND employment practices is medium THEN social sustainability is medium to high
Rule 6	IF health and safety is low AND employment practices is low THEN social sustainability is low
Rule 7	IF environmental performance is low AND green image is high AND pollution control is medium AND green competencies is high THEN environmental sustainability is medium to high

The JfuzzyLogic Java library (Cingolani & Alcalá-Fdez, 2013) was utilized for implementing the developed FIS model. The environmental, economic and social sustainability dimensions scores were obtained and tabulated in Table 10.

Table 10.
Fuzzy evaluation process output.

Dimension	Supplier		
	S.P	T.S	K.KH
Environmental sustainability (*EN*)	0.7933	0.5597	0.7413
Economic sustainability (*EC*)	0.8275	0.5668	0.726
Social sustainability (*SO*)	0.7981	0.6252	0.7319
Supplier sustainability performance score	*0.8063*	*0.5839*	*0.733*

- *Step 5: Supplier sustainability performance score*

After obtaining all of the three sustainability dimensions scores, the supplier sustainability performance value for each of the three evaluated suppliers was calculated by using Eq. 4 and shown in Table 10.

Finally, three ranges were defined to make a decision for selecting the suitable suppliers for making a contract. In order to do so, the S.S Company’s DMs were asked to assign decision making threshold for the supplier sustainability performance score. As this value is between 0 and 1, it was decided that if the supplier sustainability performance score is between the ranges of 0-0.7, it will be considered as low sustainable and the supplier will be rejected. If it is between the ranges of 0.7-0.8, it will be categorized as medium sustainable and the supplier can be accepted for making a contract in one condition that all of the *EN*, *EC* and *SO* values are individually more than 0.5. Lastly, if it is between the ranges of 0.8-1, it will be considered as high sustainable and the supplier will be accepted for further cooperation.

In this research study, the S.P supplier company holds the best sustainability performance with the value of 0.8063 which makes it to be categorized as high sustainable supplier and selected for making a contract with the manufacturer company. On the other hand, the T.S supplier company was rejected by the S.S Company as its sustainability performance score is 0.5839 which is within the low sustainable ranges. In case of the K.KH supplier company, its sustainability performance score is 0.733 which categorizes this supplier as a medium sustainable supplier. The K.KH supplier company was tentatively accepted by the S.S Company as all three individual *EN*, *EC* and *SO* values are more than the defined threshold (0.5). The K.KH has been selected as the second supplier and given a time period of one year to improve its sustainability performance score to be within the high sustainable performance ranges.

6 Results analysis and discussion

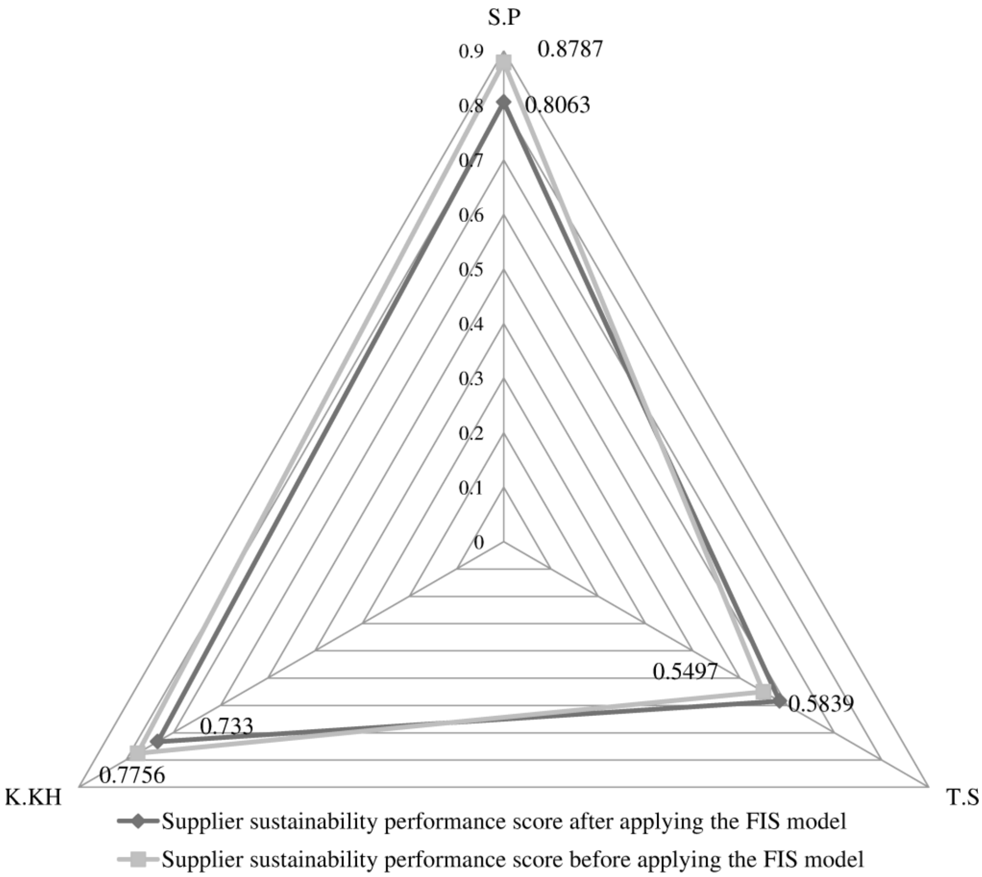
6.1 Comparisons

To our knowledge, the calculated criteria values using the audition check-list approach are not suitable to be utilized in any other sustainable supplier ranking approaches in the literature for comparison purposes. However, in order to provide more insights, we compared the three suppliers' sustainability performance scores before and after applying the proposed FIS model. Fig. 4 illustrates the results of this comparison. The results of this comparison show how applying the FIS model can change the sustainability performance scores. The scores before applying the FIS model were obtained using the results presented in Table 5. For instance, the value of environmental sustainability for the S.P supplier company was obtained by calculating the average value of its four criteria which would be EP + GI + PC + GC = 1 + 0.91 + 0.62 + 0.82 = 0.8375 (*EN*). Afterwards, the values of economic and social sustainability dimensions were also obtained using the same procedure which resulted in the final average value of the S.P Company's sustainability performance score calculated as $EN + EC + SO = 0.8375 + 0.9437 + 0.855 = 0.8787$. The same calculation procedures were performed in obtaining the sustainability performance scores of the T.S and K.KH Companies.

As it can be perceived from the results, not applying the FIS model didn't change the S.S Company's decision towards selecting the sustainable suppliers compared to the results after applying the FIS model. However, there might be some occasions that making decisions based on the subjective sustainability scores (before applying FIS model) would end up giving misleading decisions depending on the type of decision policies used. In order to elaborate more, consider the K.KH Company's sustainability performance score before applying the FIS model. Currently, the DMs in S.S Company defined a threshold value of between 0.7 and 0.8 for a "medium sustainable" level. This threshold would not change their decision towards the K.KH Company as it would be still within the medium sustainable range before or after applying the FIS model as these values are within the defined thresholds.

However, if the "medium sustainable" range was defined to be between 0.65 and 0.75, the S.S Company's decision towards the K.KH Company would be affected by the subjective sustainability score, calculated before applying the FIS model. The FIS model enables the capturing of uncertainties and subjectivities of the S.S Company's auditors while using the designed audition check-lists.

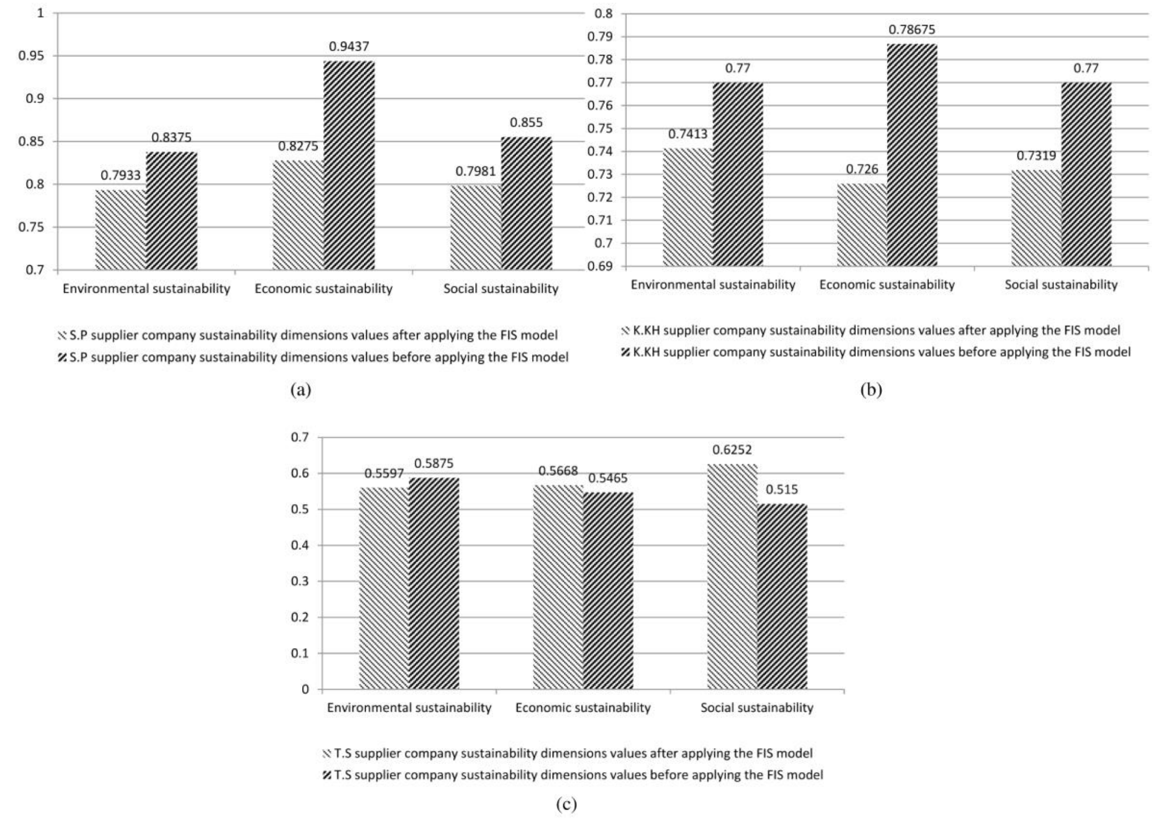
In the case of the S.P Company, this company was categorized as the "high sustainable" performing company with the value of 0.8063 after applying the FIS model. Although this value satisfies the current high sustainable threshold, the S.S Company's DMs might ask the S.P Company to improve some aspects of their operations as their sustainability performance value is at the low-level of the "high sustainable" threshold. Examining the sustainability performance value of the S.P Company before the FIS model is 0.8787 which is to a good extent above the threshold of 0.8 (defined by the S.S manufacturer company). This might give the impression to the DMs in the manufacturer company that this supplier is performing very well and does not need to improve operational activities; which could be viewed as an incorrect wrong decision by the DMs inside the manufacturer company.



[Fig. 4 near here]

In order to have a more detail analysis on the evaluation results, each supplier's sustainability performance score was broken down into the sustainability dimension values. As shown in Fig. 5, the darker hatch made columns are the sustainability dimension values before applying the FIS model. As it can be seen, in most cases the values are higher than the brighter hatch made columns which are the values after applying the FIS model. The proposed FIS model combined with the audition check-list approach mitigates the inherent subjectivities in the decision making process resulting in more reliable decision support for the DMs in the S.S Company. In particular, Fig. 5(a) shows that the original economic sustainability value that was gathered by the auditor using the audition check-list was 0.9437 which indicates that the performance of the S.P supplier company towards economic sustainability is almost perfect. This value is calculated at 0.8275 after applying the FIS model. Comparing the difference in these two values provides more precise insights about what is really going on regarding the measurement of sustainability issues in the S.P Company, and similarly in the other evaluated supplier companies for the DMs in the S.S Company.

In contrast, Fig. 5(c) shows how the FIS model altered the social sustainability results in the T.S supplier company (rejected supplier). The social sustainability performance value increased to 0.6252 which is higher than 0.515 before applying the FIS model. In this particular instance, the FIS model had a positive effect on the audition check-list result resulting in better social sustainability performance for the T.S Company. This instance can be a good indicator for proving the advantages of this approach where removing impreciseness and uncertainty from the subjective check-lists results using the FIS model posed a positive effect on the performance value rather than decreasing its value.



[Fig. 5 near here]

6.2 Sensitivity Analysis

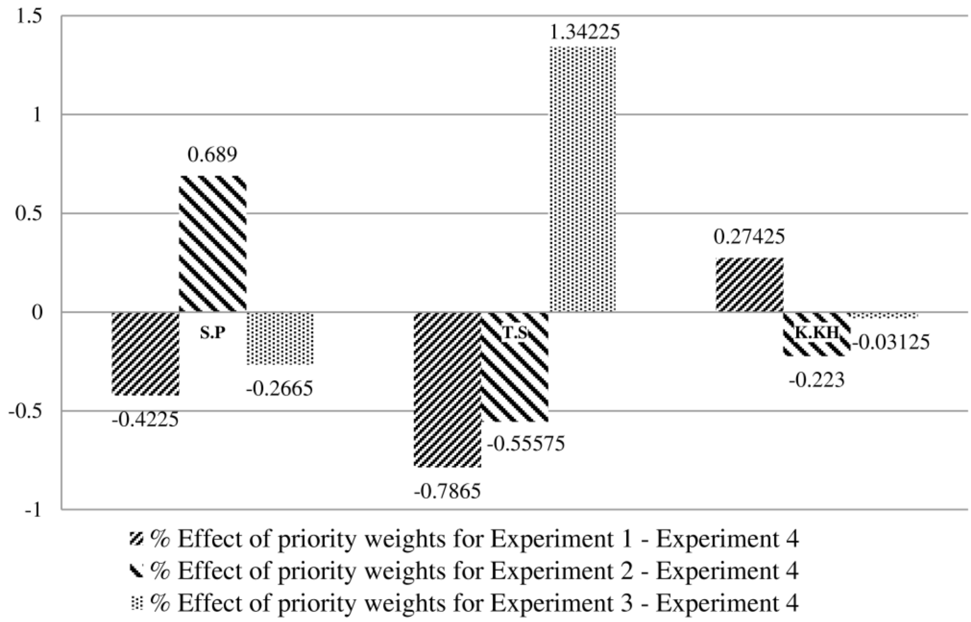
Same as any methodology and framework, the quality of obtained results is highly dependent on the quality of information derived from the data gathering stage which should not be neglected. The audition check-list approach was designed to tackle such issues in the supplier evaluation process. However, the existence of the imprecise subjective information within the process of sustainability assessment of suppliers is inevitable. Therefore, the quality of results obtained by the audition check-list approach was improved using the developed FIS that has the advantage of reducing such impreciseness to the DMs.

The sensitivity analysis process was conducted on the results of the developed approach in order to highlight the effect of variation in the three sustainability dimensions priority weights on the evaluation process and ranking of the three suppliers for sustainable adoption. The sensitivity analysis procedure developed by Prakash and Barua (2015) was adopted in this paper. They performed sensitivity analysis by replacing the high weights for decision attributes while putting all the other weights to constant. Their utilized sensitivity analysis process indicated how their proposed framework was sensitive to the criteria weights. Following the same procedure, three sensitivity analysis experiments were performed in this research activity. In the sensitivity analysis Experiment 1, weight of environmental sustainability dimension (w_{en}) = 0.55 and weights of economic sustainability dimension (w_{ec}) and social sustainability dimension (w_{so}) equal to 0.225, remains constant. The sustainability performance scores of the three suppliers are calculated by utilizing Equation 4. Again in the sustainability analysis Experiment 2, w_{ec} = 0.55 and w_{en} = w_{so} = 0.225 remains constant and sustainability performance value of the suppliers are obtained and the suppliers are ranked. Similarly, sensitivity analysis Experiment 3 was also performed. These three experiments were compared with the original results (named Experiment 4) where equal importance was considered for the three sustainability dimensions. The results of the sensitivity analysis are shown in Table 11. For this particular case, the sensitivity analysis shows that still the S.P supplier company is the most sustainable supplier in all experiments. This mainly occurred as the performance of the S.P is much better than the other two suppliers; therefore, assigning priority weights to the sustainability dimensions did not change the ranking orders of the three suppliers. The effect of these weights could be increasingly highlighted in cases where the sustainability performance score of considered suppliers is relatively close to each other.

Table 11.
Sensitivity analysis results.

Experiment	Weights	Sustainability performance score		
		S.P	T.S	K.KH
1	w_{en} = 0.55, w_{ec} = 0.225, w_{so} = 0.225	0.802075	0.576035	0.735743
2	w_{ec} = 0.55, $\mathrm{w_{en}}$ = 0.225, $\mathrm{w_{so}}$ = 0.225	0.81319	0.578343	0.73077
3	w_{so} = 0.55, w_{en} = 0.225, w_{ec} = 0.225	0.803635	0.597323	0.732688
4	w_{en} = 0.333, w_{ec} = 0.333, w_{so} = 0.333	*0.8063*	*0.5839*	*0.733*

Fig. 6 shows the effect of considering the priority weights on the evaluation process of each supplier in percentage. This effect was measured by subtracting the sustainability performance scores in sensitivity analysis Experiment 4 from the sustainability performance scores of sensitivity analysis Experiments 1, 2 and 3. This means that sensitivity analysis Experiment 4 (equal weighting) was considered as a base line and all the other experiments were measured against it. In most cases applying the priority weights have a decreasing effect on the sustainability performance score of the three suppliers. However, an increasing effect occurred in three cases. The maximum effect of the priority weights on the evaluation results among all of these cases is 1.34225%, whereas, the minimum effect is -0.7865%. It indicates that the proposed approach is relatively sensitive to the criteria weights.



[**Fig. 6** near here]

7 Research Findings, Implications and Managerial Insights

The conducted research contributes to the theory of sustainable supplier selection and sustainable supply chain management by proposing a data gathering approach and also an FIS model aiming at capturing the uncertainty and inherent subjectivity of gathered input data related to the evaluation process of a potential supplier with regards to sustainability attributes. This assessment approach differentiates itself from other approaches in the literature by capturing the social aspects of the sustainability together with environmental and economic practices. This work narrows the theoretical gaps that were identified by Longoni and Cagliano (2015) and Meixell and Luoma (2015). They investigated the effects of blending environmental and social aspects of sustainability into business operations. It was concluded that companies that incorporate the environmental and social sustainability into their traditional price-based configuration models will show better performance in both short-term economic performance and long-term sustainable and operational performance.

The objective of this case study was to rank and select the sustainable suppliers that are capable of procuring the required components for the manufacturer company. The proposed approach transfers the traditional supplier selection system to the sustainable supplier selection by incorporating environmental and social criteria. By examining six criteria and 24 sub-criteria related to environmental and social dimensions, this research study helps the S.S Company's managers to understand the principles of sustainable supplier evaluation and process and offers the following benefits.

The first benefit of this study is developing environmental and social criteria and sub-criteria based on a literature review and input from the S.S Company's DMs. Secondly, many research works provided approaches for evaluating green SCs with few works considering sustainable SC. However, most of them provide numerical examples to illustrate the impact of their developed approach. This matter was identified as an issue by recently published review papers analysing the practicality of these approaches (Brandenburg et al., 2014; Ghadimi et al., 2015; Govindan, Rajendran, et al., 2013). S. Kumar et al. (2012) also highlighted that proposing such framework and demonstrating it using a real application offers more realistic insights into the actual readiness of companies to integrate sustainability into their SC operations and practices. By integrating sustainability tools into SC activities of a real case company, our study shows that social and environmental sustainability initiatives can expand and improve the traditional supplier selection process in a typical manufacturing company.

Besides, the proposed approach also narrows the practical gap identified by Danese (2013) where they found that literature still lacks practical approaches that can help manufacturing organizations to perform a fast and efficient assessment of their suppliers. Towards this end, we focused on proposing an approach for practitioners to measure their suppliers' sustainability performance with minimized uncertainty in input data and providing hybrid tools to analyse this data in their decision making process. The result of this study helps companies to make the best decision regarding the selection of the sustainable supplier within the set of sustainability dimensions and their selected criteria.

8 Conclusion and Future work

In today’s competitive business environment, being able to measure the complexity of an organization’s performance in conducting sustainable practices is critical and of great importance. In industry, top managers have an influential effect on their organization’s advancements towards adopting and implementing sustainable practices. In the SSCM context, one of these sustainable practices that might affect the operational activities of the entire organization is selecting the best supplier(s) that can procure components aligned with a manufacturer’s requirements in terms of predefined sustainable criteria. Therefore, providing precise decision making assistance for top managers as main decision makers of a firm would be beneficial for a firm’s successful movement towards implementing sustainable sourcing operations. In order to achieve this goal, manufacturing organizations need a performance assessment technique that can provide a structured procedure in order to rank the potential suppliers based on the TBL attributes. This was the motivation for the current research activity.

In this paper, the sustainable supplier selection problem was investigated in the automotive spare part industry with the aim of proposing an approach for both the sustainable supplier evaluation data gathering process and also sustainable supplier selection decision making process. Using this approach, the most important criteria and sub-criteria related to environmental and social sustainability dimensions were selected based on the DMs aggregate opinions. Using these selected factors and the ones extracted from the company’s management system for economic aspects of sustainability, three sets of audition check-lists were designed and validated for facilitating the process of supplier evaluation. The audition results were then utilized as input values for the designed FIS model which can cope with imprecise subjective values. In the paper, the output results of the FIS model were compared with the output values of the audition check-list to highlight how human subjectivity and vague opinions can negatively affect the decision-making process. A sensitivity analysis was done to determine the changes in the results that are relative to the changes in sustainability dimensions weightage. Finally, it is worth to mention that while the developed approach can be generic, the formulation of sustainability criteria and sub-criteria are related to the industry that the case company is operating within. Therefore, the practitioners in other type of industries will need to alter the criteria sets to satisfy their own requirements to evaluate and select their best sustainable supplier(s).

Appendix

Social sustainability assessment related questions

Question	Criteria	Answer choices

number (Q_{ki})		
	Health and Safety (HS)	
Q_{11}	What certification does the supplier have?	OHSAS 18001; Being Implemented; Non
Q_{21}	What is the potential number of injuries for the workers in the production floor?	Less than 2; Between 2 and 5; 5 and more; Not Measured
Q_{31}	What is the potential level of fatalities during manufacturing of various products?	Low; Medium; High
Q_{41}	Do they have a health and safety department in the company?	Y/N
Q_{51}	Do they have a health and safety practices in the company?	Yes; Yes but insufficient; No
Q_{61}	Do they have any plan for improving the working environment conditions?	Yes; Yes but not systematically; No
Q_{71}	Does the supplier have Material Safety Data Sheets (MSDSs)?	Yes; Yes but insufficient; No
Q_{81}	Do you think that this supplier is capable of working with S.S Co. regarding the environmental performance criterion?	Perfectly convinced; Rather convinced; Rather unconvinced; Unconvinced
	Employment Practices (EmP)	
Q_{12}	Do staff in the supplier company have job stability?	Yes; Yes but insufficient; No
Q_{22}	Do they have any plan for increasing the job opportunities every year?	Yes; Yes but not systematically; No
Q_{32}	Do they have child labor?	Y/N
Q_{42}	Does the supplier have any program for job rotation in order to have job promotions?	Yes; Yes but not systematically; No
Q_{52}	Do they have any program for educating the employees while they are working?	Yes; Yes but insufficient; No
Q_{62}	Do they have any program for employee welfare?	Yes; Yes but insufficient; No
Q_{72}	Do they have flexible working arrangement?	Yes; Yes but not systematically; No
Q_{82}	Do you think that this supplier is capable of	Perfectly convinced;

	working with S.S Co. regarding the employment practices criterion?	Rather convinced; Rather unconvinced; Unconvinced

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Figure Captions

Fig. 1. The proposed approach steps.

Fig. 2. The proposed FIS model.

Fig. 3. (a) Membership function for each sub-criterion. (b) Membership function for defuzzification process.

Fig. 4. Supplier sustainability performance score comparison before and after applying FIS model.

Fig. 5. (a) The S.P supplier company sustainability dimensions value before and after applying the FIS model. (b) The K.KH supplier company sustainability dimensions value before and after applying the FIS model. (c) The T.S supplier company sustainability dimensions value before and after applying the FIS model.

Fig. 6. Effect of considering the priority weights on sustainability evaluation process in percentage.